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A Model for In-service Teacher Learning in the Context of an Innovation

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Abstract When curricula change, teachers have to bring their knowledge and beliefs up to date. Two aspects can be distinguished: *what* do teachers learn and *how* is it learned. Two groups of teachers were involved during the preparation of a new chemistry curriculum. One group developed student learning material and subsequently enacted this in class. Another group only class-enacted this. Based on teacher learning, a model to understand teacher growth is presented. As the combination of a *development phase* with a *class enactment phase* proved instrumental, an existing model, the interconnected model of teacher professional growth, was extended. The consequence is that for teacher learning for a renewal a *(re)development phase* followed by a *class enactment* phase is essential.

Keywords Teacher professional growth · Professional development · Model for professional development · Teacher learning model

Introduction

A new context-based chemistry curriculum for upper high school, initiated in 2003 in the Netherlands (Driessen & Meinema, 2003), was implemented nationwide in September 2013. The most important characteristic in this kind of education is that appealing contexts for students are used as a starting point for learning. Context-based education adopts the view that science content follows 'naturally' from an

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authentic context, is therefore developing and flexible (Bencze & Hodson, 1999; Gilbert, 2006), and definitely not just a set of rules and principles to be memorized. Specific forms of context-based chemistry education were developed in different countries such as the USA (Schwartz, 2006; Schwartz et al., 1997), UK (Bennett & Lubben, 2006; Campbell et al., 1994) and Germany (Parchmann et al., 2006; Ralle, 2001). These experiences served as inspiration for the Dutch curriculum developers. Another important characteristic of the new Dutch context-based chemistry curriculum is the focus on two central concepts: the particle concept (all matter consists of small particles such as molecules, atom, ions) and the micro–meso–macro concept [the structures at molecular level determine properties at meso- and macro-level (Meijer, 2011)].

Initiating a new context-based chemistry curriculum implies a curriculum change. A curriculum change affecting classroom practices is complex, having an effect on the development of various curriculum components such as learning materials, instructional strategies and assessment methods and instruments (Loucks-Horsley & Matsumoto, 1999). Teachers play a crucial role in curriculum changes, as they are the ones to implement the new curriculum in class (Fullan, 2007). This means that teachers need to bring their knowledge and beliefs in line with the new curricular demands (Cotton, 2006; Pintó, 2005). Therefore, teacher learning is necessary in order to realize the curriculum change, and this is not an easy endeavor (Davis, 2003; Doyle & Ponder, 1977; Duffee & Aikenhead, 1992).

The Dutch National Steering Committee, responsible for the development of the new context-based curriculum, recognized the important role teachers play and decided to involve teachers in the design of student learning material through participation in teacher development networks (Driessen & Meinema, 2003). It was supposed that participation would increase teacher ownership of the context-based curriculum and would lead to changes in knowledge and beliefs of these teachers, meaning that teachers would professionalize in the course of this process.

Teacher Learning

Two aspects are important in teacher learning: (a) What is learned? and (b) how is it learned?

What is Learned?

The knowledge and beliefs teachers use in their teaching in class has been described as pedagogical content knowledge (PCK) (Shulman, 1987). Several authors have further defined and elaborated on PCK (Abell, 2008; Loughran, Mulhall, & Berry, 2008; Park & Oliver, 2008; Schneider & Plasman, 2011; Van Driel, Verloop, & De Vos, 1998). Changing to a context-based curriculum requires teachers to change their practices and beliefs, not just with respect to materials, pedagogies and assessment, but even with respect to purposes and goals of science teaching and beliefs about science teaching and learning. In agreement with Magnusson, Krajcik and Borko (1999), we adopted in earlier studies (Coenders, 2010; Coenders et al., 2008, 2010) the following PCK components: (1) orientations toward science teaching, (2) knowledge and beliefs about the science curriculum, (3) knowledge and beliefs about instructional strategies, (4) knowledge and beliefs about students' understanding of specific topics and (5) knowledge and beliefs about assessment. The first four of these five PCK components are used in this study; because little attention was given to assessment, it was supposed that the last component would not be affected. These four PCK components are used for coding the change in knowledge and beliefs of teachers participating in a context-based curriculum (see further data analysis). Several scholars described the importance of class enactment, individual reflection and collective reflection in order to develop PCK (Rollnick, Bennett, Rhemtula, Dharsey, & Ndlovu, 2008; Van Driel & Berry, 2012).

How is it Learned?

Guskey (1986) presented a model in which professional development activities lead to changes in classroom practice which may result in improved student learning and this finally brings changes in teachers' knowledge and beliefs. As this model is rather static and cannot easily account for observed changes, it is not so useful for our study. Clarke and Hollingsworth (2002) elaborated a model based on professional teacher activities and called this the Interconnected Model of Professional Growth (IMPG). This model, presented in Fig. 1, shows possible pathways through which professional knowledge can grow. The authors distinguished four domains: a personal domain where teachers' knowledge, beliefs and attitudes are located; the domain of practice containing all kinds of professional experimentation, including the enactment of learning material in class; the domain of consequence encompassing all salient outcomes of the experimentation domain; and the external domain consisting of all sources of information or support

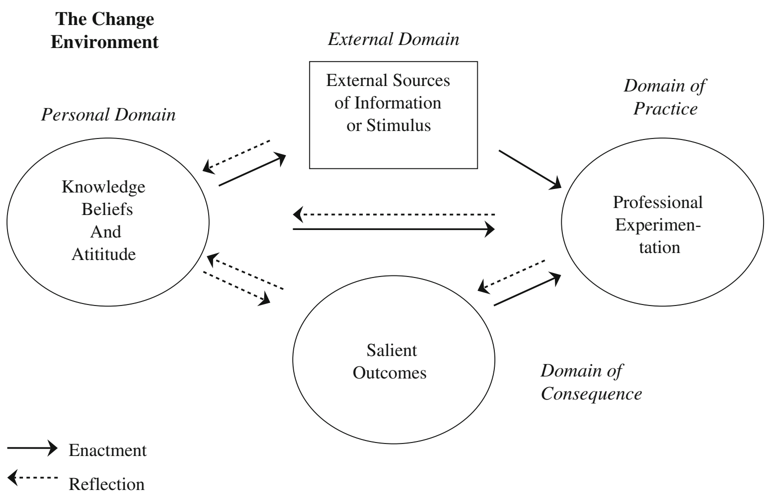

Fig. 1 Interconnected Model of Professional Growth (IMPG) (Clarke & Hollingsworth, 2002)

emerging from outside the teachers daily professional world. These four domains can influence one another through mediation processes of 'reflection' and 'enactment.' 'Enactment' was used because the teacher needs to translate a belief or a pedagogical model before class use, which is clearly different from just 'acting' (2002, p. 951).

The process by which changes occur is represented as a 'change sequence' consisting of 'two or more domains together with the reflective or enactive links connecting these domains, where empirical data support both the occurrence of change in each domain and their causal connection' (2002, p. 958). Where the occurrence of change is more than momentary, this change is seen as professional growth and the associated change sequence is termed a 'growth network.' We will use IMPG as a framework for data analysis in order to analyze and to understand teacher professional growth (see further data analysis).

Several studies displayed the potential of the IMPG to analyze and to understand teacher professional growth. Justi and Van Driel (2006) successfully used the IMPG as a framework to establish the relationships between the different data gathered in characterizing the growth of science teachers' knowledge on model and modeling. Eilks and Markic (2011) could make the knowledge growth comprehensible in a 6-year participatory research project of chemistry teachers and educators by using the framework of the four IMPG domains and the PCK model. Witterholt, Goedhart, Suhre and van Streun (2012) used a number of 'cycles of change' of the IMPG to describe the development of a mathematics teacher when she was challenged to redesign her lessons during network meetings with her colleagues. Clarke, Hollingsworth and Gorur (2013) used video recordings of lessons as external sources of reflection in the IMPG framework in order to analyze mathematics teacher knowledge changes. However, the potential of IMPG as analysis framework is not known for the professional knowledge growth in a specific professional development program for curriculum change.

Methods

Context of the Study and Research Question

As it was anticipated by the National Steering Committee that not all teachers could become designers of learning material, automatically two different groups of teachers came into being: teachers involved in the development *and* enactment of context-based student learning material, named *teacher-developers/enactors*, and teachers not involved in the development but merely enacting the new material in class, called *teacher-enactors*.

One network to develop student learning material from scratch suitable for context-based chemistry education was set up in our region. This network consisted of three chemistry teachers under supervision of a chemistry coach, all participated voluntarily. This network developed, subsequently class-enacted, and finally revised student learning material. This material was then used in class by five teacher-enactors who also participated voluntarily. We observed that teacher-developers/

enactors changed their PCK knowledge and beliefs and that teacher-enactors hardly developed new PCK (Coenders, 2010; Coenders et al., 2010).

This resulted in the following *research question*:

> Taking into account that material development is a crucial part of teacher learning, does the extension of the IMPG-framework with a Developed Material Domain lead to an intelligible interpretation and understanding of the changes in teachers' PCK-knowledge and -beliefs?

Participants

In the following section, relevant particulars of the three participating teacher-developers/enactors and the five teacher-enactors are specified. All teachers had experience at high school-level teaching, and all had taught Form 3 (for which the module was developed). The teacher's names are fictitious.

The three teacher-developers/enactors, Pete, Lisa and Ed, had, respectively, 5, 12 and 30 years of teaching experience; all had a master degree in chemistry plus a teacher qualification and participated voluntarily. They were employed by three different schools and were released for half a day per week to participate in this development network. The coach of these teacher-developers had been a chemistry teacher for more than 30 years, was an experienced author of chemistry books and was now employed by the teacher training department of a university.

The teacher-enactors, called Ann, Art, Iris, Hank and Gene, also participated voluntarily in this study. Four held a master degree in chemistry plus teacher qualification, Hank being the only exception; he had completed a 4-year professional teacher training program. Art had 2 years of teaching experience, Hank five, Iris nine, and Ann and Gene 30 years. Art and Hank were employed by the same school, and the others worked at different schools in the region.

Procedure and Materials

In an iterative and cyclic process under supervision of the coach, the teacher-developers/enactors, Pete, Lisa and Ed, developed student learning material in a time frame of 7 months. This learning material took the form of a module for about eight periods holding all texts, exercises, assignments and practical work for the students. The network selected the context of the module, the concepts to be learned, the instructional strategies to be used and the way student learning would be assessed. The context of the module was 'baking a cake' and was meant for Form 3 students (14- to 15-year-olds) to be used by the end of the school year. Chemistry is taught for the first time in Form 3. Several concepts were addressed in the module: What is a chemical reaction and how can one determine whether a process (like baking a cake) is a chemical reaction, the law of conservation of mass (Lavoisier's law), process charts to describe chemical processes (on paper and on a computer) and upscaling a process (baking as example). The students would work in cooperative groups of four or five students, having each period revolving roles, such as chairperson, writer, material chief, time keeper and questioner. Material to assist students to cooperate successfully was also developed: a group log to keep track of progress and process and materials to teach students specific cooperative skills (Ebbens, Ettekoven, & Rooijen, 1996).

In the period of 7 months, nine network sessions of each 3–4 h took place, where all participants met to discuss progress. In between the sessions, participants informed one another through e-mail. After completion of the module, the teacher-developers/enactors enacted the material in their own classes, subsequently discussed the results and revised the module for use by the teacher-enactors. A concise teachers' guide was developed. The full process took one school year.

The five teacher-enactors voluntarily enacted this module in their classes. To prepare these teachers for class use, a half-day workshop was organized in which the teacher-developers explained the rationale of the module and shared their experiences with the teacher-enactors, in which opportunities were offered to become familiar with and practice innovative aspects from the module.

Two key aspects of the module were as follows: (a) a *context-based approach*. The learning material started from a context in which students would explore concepts using multiple activities, and (b) *cooperative learning* as the pedagogy in the module. All teachers were familiar with the chemistry content addressed in the module, but the context-based approach and cooperative learning were new to all.

Research Design

Multiple case studies (Yin, 2003) have been used to portray the changes in knowledge and beliefs of these teachers. The main reason for this approach is that capturing teacher knowledge and beliefs is complex (Pajares, 1992). Moreover, each teacher as a 'case' is unique; teacher learning is therefore seen as an idiosyncratic process (Borko, 2004; Clarke & Hollingsworth, 2002; Parke & Charles, 1997).

Instruments

Data were collected through interviews, questionnaires, transcribed audio recordings from network meetings (where the teachers discussed the student learning materials under development) and the developed module.

The teacher-developers/enactors were interviewed and filled in a questionnaire before the development process started. After finalizing the module but before class enactment, each teacher-developer/enactor was interviewed again. After having used the material in class, each teacher-developer was interviewed once more. All interviews lasted between 1 and 2 h.

The teacher-enactors were interviewed before class use, but after the workshop where the material was explained, and after class use. Nine open questions were posed before class use, and fifteen, including factual questions related to class use, after enactment. All interviews were conducted at school and lasted between 40 and 80 min.

The 'Appendix' shows a time frame for the interviews, and some of the posed questions.

Data Analysis

All interviews were transcribed and analyzed starting with a process of open coding, followed by axial coding (Gibbs, 2007). Open coding resulted in relevant categories for changes in teacher knowledge and beliefs. Axial coding resulted in a redefinition of the categories in relation to the five previously defined PCK areas and led to two key aspects we will report on in the results section: knowledge and beliefs on (a) the context-based chemistry approach and on (b) cooperative learning. The domain 'knowledge and beliefs on the context-based chemistry approach' is partly situated in the PCK component 'orientations toward science teaching' when it comes to the purpose and goals for chemistry education. But it is also located in the PCK 'knowledge and beliefs about the science curriculum' component with respect to teaching for understanding and the activities and materials in meeting the specific goals. And it is also located in the domain 'knowledge and beliefs about students' understanding of specific topics' when it comes to chemistry concepts and the relations between these concepts. Knowledge and beliefs on cooperative learning are situated in the PCK component 'instructional strategies.'

The coded passages were transferred to word tables. The developed materials and the network meeting transcripts served as triangulation instruments (Denzin & Lincoln, 2000; Meijer, Verloop, & Beijaard, 2002). The coded passages were connected to the relevant EIMPG domains, and the enactment and reflection processes were subsequently identified. Examples of results in the different phases of the coding process have been published previously (Coenders, 2010; Coenders et al., 2010).

Results

In the first section, the IMPG model in this study context will be elaborated, and the relation between the IMPG and teachers' PCK. Then the extended model (EIMPG) will be described and linked to teacher learning and how this learning is envisaged.

IMPG in this Study Context

Personal Domain Teacher knowledge and beliefs (PCK) is located in the personal domain (Fig. 1), and the goal of the study with the teacher-developers/enactors and with the teacher-enactors was to establish the effect of the activities on this personal domain (PCK).

Ext*ernal Domain* The external domain for the teacher-developers/enactors in our study comprised of several interventions and materials to expand teacher-developers/enactors' PCK: (a) network meetings with emphasis on discussing the learning materials 'under construction' in the different stages and its influence on student learning. These network meetings also served to build commitment and prepare for class enactment, (b) documents about context-based chemistry, for example from the National Steering Committee that initiated this reform, (c) previous experiences from one teacher-developer served as learning opportunities and mirrors for the others, (d) specific literature, for example on cooperative learning and how student progress can be monitored, (e) expertise from the coach, especially with the development of student learning material.

For the teacher-enactors, this external domain was limited and consisted of a half-day workshop.

Domain of Practice For both teacher groups, this domain consisted of the class enactment of the student learning material. In this domain, teachers bring their PCK to practice.

Domain of Consequence Salient student learning outcomes are part of this domain.

Interaction between the domains occurs either through *enactment* or through *reflection*. Two examples below show how reflection and enactment for the teacher-developers/enactors are envisaged. First reflection between the external and personal domains will be described, followed by enactment between these two domains.

Reflection on the external domain influences the knowledge in the personal domain (Fig. 2 or 4, arrow 1). Experiences and practices from one teacher are part of the external domain for others. Exchanging experiences during network sessions catalyzed reflection on own practices. A teacher-developer/enactor, who shared experiences about learning activities, materials or instructional methods and how students react to these, was given a reflection mirror through the questions the other network members posed about the described practice. For the other teacher-developers/enactors, these experiences formed a framework through which they assessed their own practices. This exchange of experiences is powerful as it deals with real class practices. Discourse at network meetings had similar effects: When the discussion revolved about the use of contexts in class each participant reflected on own experiences and practices, therein connecting the external domain with the personal domain.

Enactment from the personal domain to the external domain (Fig. 2 or 4, arrow 2) can be portrayed as follows: Teacher-developers/enactors had to become aware of personal teaching experiences interesting enough to share with the others. This process was not just a matter of selecting and sharing, but first of translating these experiences to make them accessible for the others. During discourse at network

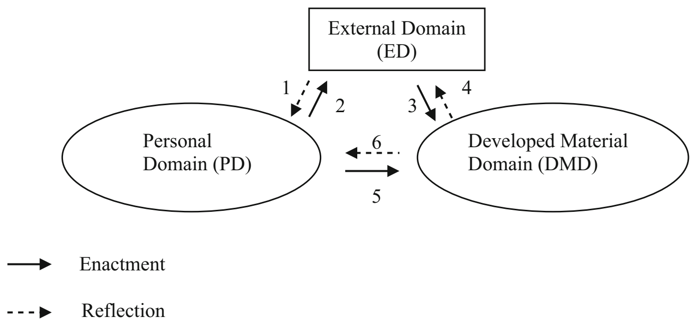

Fig. 2 Model of the *development phase*

sessions, a similar enactment process arose: A teacher-developer had to get his own framework clear to be able to contribute.

Analogous interactions in the form of reflection or enactment occurred between the other domains of Figs. 1, 2, 3 and 4.

Extending the Interconnected Model of Professional Growth

Within-Case Analysis for Two Case Groups

The three teacher-developers/enactors, Pete, Lisa and Hank, did acquire PCK both during the *development phase* of the material and during the *class enactment phase*. They developed context-based education in which cooperative learning is the main instructional strategy and noticed in class how this affected students' learning. This brought about changes in the following PCK components: in 'orientations toward science teaching', in 'knowledge and beliefs about the science curriculum' and in 'student learning of specific topics.' And as two teacher-developers/enactors used cooperative learning in their classes, they also developed knowledge on the PCK component 'instructional strategies.'

The five teacher-enactors, Ann, Art, Iris, Hank and Gene, did acquire PCK only in the class enactment phase. This brought about changes in the following PCK components: 'science curriculum' and in 'instructional strategies,' but none in 'orientations toward science teaching' or in 'understanding specific topics.'

A Cross-Case Analysis for Two Case Groups

The PCK learning of the five teacher-enactors was limited compared to the teacher-developers/enactors.

The main reason for this difference with teacher-developers/enactors is that teacher-enactors not only were not involved in the discussions during the development of the material, but they also did not enact the material as intended.

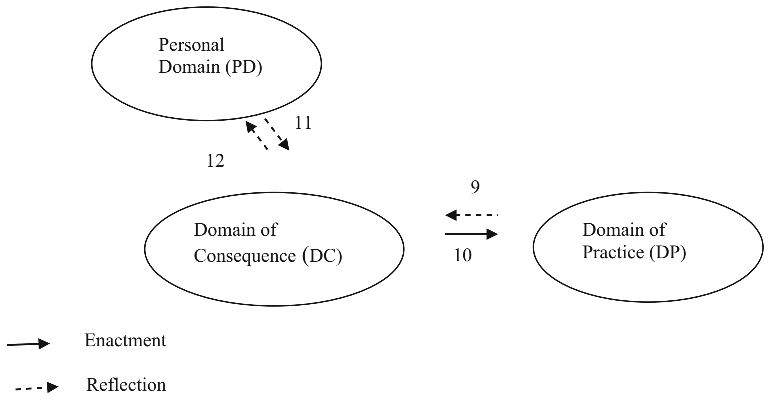

Fig. 3 Model of the *class enactment phase*

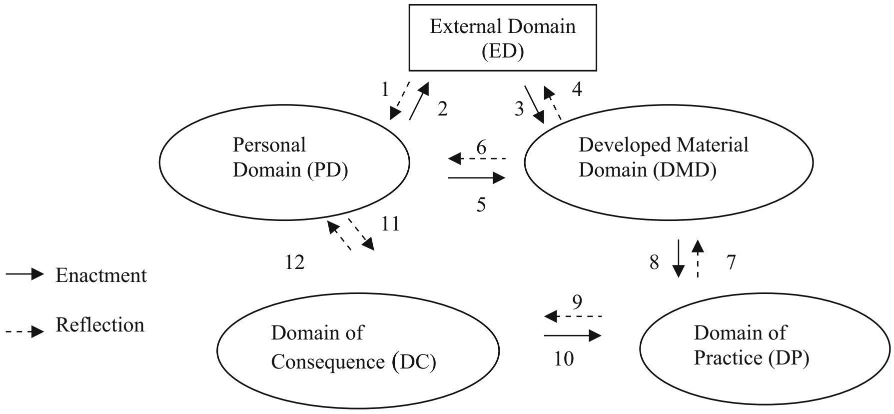

Fig. 4 Extended Interconnected Model of Teacher Professional Growth (EIMPG)

Except Iris, all made adaptations to the module before class use: They either made substantial changes removing innovative aspects of context-based education or implemented only those parts they were already familiar with.

All these changes in teachers' PCK knowledge and beliefs have been reported in detail elsewhere (Coenders, 2010; Coenders et al., 2010).

Extending the Model with a Developed Material Domain (DMD)

Comparison of teacher-developers/enactors' learning with teacher-enactors' learning showed that the *development phase* not only facilitated better implementation of the module but also substantially contributed to the changes in teacher knowledge, beliefs and attitudes. We will demonstrate the contribution of the development phase below. This led to the conclusion that the *development phase*, followed by the *class enactment phase*, was instrumental for teacher-developers' growth. To accommodate for the fact that the learning material 'under construction' substantially contributed to teacher growth, the Clark and Hollingsworth IMPG model is extended with one extra domain, the developed material domain (DMD). This extension is shown in Fig. 2, and this extension will lead to the Extended Interconnected Model of Teacher Professional Growth (EIMPG).

In the following sections, we will highlight key aspects in teacher growth in relation to the EIMPG model: first, an analysis within the case groups for the three teacher-developers/enactors and the five teacher-enactors, and next an analysis across these case groups.

Within-Case Analysis for Two Case Groups

Modeling Teacher-Developers/Enactors' Growth

First, the processes with respect to '*context-based approach*' and '*cooperative learning*' in the *development phase* will be highlighted. Then it will be illustrated how interactions between domains, particularly the added domain (DMD), have caused changes in the knowledge and beliefs systems from Pete, Lisa and Ed. We will continue with the *class enactment* phase.

As space is limited, the focus will be on Pete's learning.

Development Phase

Context-Based Approach The development of the material started with reading and understanding the documents from the National Steering Committee, a process of getting grip on the rationale of the context-based approach. In the next step, potential contexts were generated and discussed and this resulted in the context 'baking a cake.' This context was subsequently further elaborated. Concepts that followed naturally from this context were identified, and some were selected on the basis of perceived importance. In the next phase, these selected concepts were linked to potential student learning activities, and finally learning strategies and pedagogies were included. Because all the elements described above (rationale, context, concepts, learning activities, pedagogies) are strongly related, the development process was far from linear, and the discussion went back and forth between context, concepts, learning activities and pedagogies. The result was that the development of the module showed a revolving approach. The discussions in each meeting brought about the arguments to make changes to the module under construction: additions, adaptations, reshuffles, and sometimes eliminations of texts, assignments and practical activities.

Cooperative Learning During the writing phase, all three teacher-developers/enactors acquired knowledge and skills with respect to the why and how of cooperative learning (the PCK component 'instructional strategies'). Group size and roles were discussed, and possible roles that would fit this context were identified and defined. Specific literature informed the team. The use of different materials to get grip on cooperation skills and how to teach these to students were discussed. The advantages and disadvantages of a group log to monitor student learning were debated, and an exemplary group log was developed. Looking at the discussions, also here revolving processes emerged: Initially, groups of two students would cooperate, and then larger groups. When concerns surfaced about whether students would be able to cooperate effectively and how the teacher would know this, the group log was definitely included.

The Teacher-Developers/Enactors' Growth in the Development Phase

Pete In the model of Fig. 2, changes in beliefs with respect to *context-based chemistry* are visualized by the following sequence. Before the writing process, Pete said that he used to think in concepts rather than in contexts, and he considered the change he was about to make as a 'leap in the deep.' He preferred recipe practical activities. When a context had to be used, he had a strong preference for one close to students' life, and as example he mentioned a home barbeque: When food turns black, students should recognize this as the chemical concept 'decomposition.' Pete introduced these ideas and preferences from his personal domain (PD) in the discussions in the external domain (ED) (arrow 2) in the group meetings. His reflections on these discussions, and on the documents from the National Steering Committee about the context-based approach, reshaped his personal domain (PD) (arrow 1) as his ideas about the role of a context changed. Pete's and other participants' perceptions were in a discourse process at network meetings (ED) translated into initial learning material (DMD) (arrow 3): The context that was chosen was 'baking a cake,' and most of the practical activities were rather open. Initially, a large number of concepts were identified to be included. Pete had a preference for students to learn concepts and expressed to find developing skills less important. Reflection on this initial material in the discourse at a next meeting (arrow 4) resulted in changes and additions in this material (arrow 3), especially in a reduction of the number of concepts and in the inclusion of specific skills. Pete even introduced the use of a spreadsheet for calculations. Pete's reflections on this material (arrow 6) resulted in new awareness and ideas with respect to teaching and learning from a context. Pete, however, still had doubts about what students are to learn and about his own role in it (arrows 5, 6). Just before introducing the developed module in class, he made some minor changes to suit his preferences (arrow 5). During this development phase, Pete learned how to develop learning material starting from a context in which students explored concepts using multiple open activities. In an interview just before class uses, Pete noted: 'Is the module challenging enough for the students? I find it an exciting endeavor' (the PCK component 'knowledge and beliefs about the science curriculum'). Pete still needed to be convinced through class enactment.

The changes in knowledge and beliefs regarding *cooperative learning* can be described with the following sequence. Pete (PD) had not used cooperative learning earlier, but wanted to try this, and literature about cooperative learning was studied (ED) (arrows 1, 2). After long discussions at the network meetings, cooperative learning was included in the learning material (DMD) (arrows 3, 4). This did not conflict with his beliefs (arrows 5, 6) as he acknowledged positive aspects in using cooperative groups, especially the possibility to differentiate. He was, however, hesitant about students' abilities to continue working on their own and wondered whether there would be an instrument to monitor students learning, he said: 'we can ask them (*the students*) to fill out separate paper sheets but we also need to go towards some sort of assessment of the module.' This discussion resulted in the development of a specific group log. Pete said that he wanted to pay 'specific attention to the group process and the explicit reflection.' In the same interview, he acknowledged that using cooperative learning was quite new: 'looking back I have been very teacher centred.' Through the discussions and the development of the learning material, Pete learned the why and how of cooperative learning, and he therefore decided to enact it in his classes.

Class Enactment Phase

In Fig. 3, a model of the class enactment phase is shown. How the model can account for the teacher-developers' growth is illustrated below.

Pete Before taking it to class, Pete still had doubts about the material: Do students learn enough and can they work on their own. Pete noticed in class (DP) that the chosen context did engage students with activities and created enthusiasm (arrows 9, 10). Pete considered, however, student concept learning insufficient (DC) (arrows 9, 10), and this influenced his beliefs (PD) as he expressed that he now considered concepts more important than the context (arrows 11, 12). He noticed that a context-based approach is possible, but getting the concepts clear and relating these to build a concept structure is extremely important. After class use, he made the suggestion to include a concept map in the material. Although Pete before the development process preferred practical activities from a recipe, he observed that open research experiments were very motivating for his students. This, however, did not automatically lead to concept development, and he wanted to scaffold this aspect. In the interview after class use, Pete said: 'I wanted to have more time at the end to reflect with the students on the concepts learned.' A bit later, he reflected on past experiences: 'I used to make a concept map with the students of all the concepts learned so far. ………… I would love to include this in the module.'

Experiences in class in fact determined how Pete finally perceived context-based education. Pete also learned that the quality of the learning material, especially the formulation of texts and the wording of assignments, has an impact on the degree in which the groups can work independent from the teacher. In an interview after class enactment, Pete said: 'what I saw is that using clear instruction in the material can reduce manpower in class by half' (arrows 9, 10, 11, 12).

Class enactment of cooperative learning (DP) showed that students needed time to get used to working in groups, as Pete expressed: 'Initially three students watched one student pour a solution in a test-tube in his right hand into another solution in a beaker in his left and all observed a colour change, this took 10 min, that was not very effective' (arrows 9, 10). The group log even played a more prominent role than anticipated. Pete decided to mark each log after every period, and he observed that this made the students look back at the previous period and naturally established a connection between the previous and the current lesson. The marking also stimulated students' reflection on both the process and the content (arrows 9, 10, 11, 12). Granting the students more responsibility worked out well, and the student results were good. All this influenced his personal domain (PD) in the sense that his knowledge and beliefs about cooperative learning was confirmed (arrows 11, 12).

Finally, Pete said that he personally needed time to get used to the different role he had in class. He used to determine pace and content as a teacher-centered practitioner, but now had to coach and assist student groups working on their own (arrows 9, 10, 11, 12).

Modeling Teacher-Enactors' Growth

In terms of the EIMPG model, the external domain for this group of teachers-enactors was very limited. As they did not develop the material, there were no network sessions, and therefore, the documents from the National Steering Committee were not discussed, teaching experiences were not exchanged, no 'materials under construction' were discussed, and no specific literature was consulted, except the concise teachers' guide supporting the learning material. This resulted in the teacher-enactors making substantial personal adaptations to the learning material (DMD) (Fig. 2, arrows 5, 6) *even before class use*. Because these teacher-enactors missed the *development phase*, they did not have a clear picture of context-based chemistry. In the *class enactment phase*, they did not use the materials in class (DC) as intended by the teacher-developers, resulting in disappointing students' learning results (DC) and few changes in the teacher-enactors' knowledge and beliefs. Actually, these teacher-enactors did not use the opportunity to change their knowledge and beliefs in the direction of the renewal, but instead adapted the material to suit their knowledge and beliefs.

As Iris was the only teacher not having made adaptations to the module before class enactment, we will describe her development using the EIMPG domains. Iris realized (PD) that it would not be easy to use the module as such as she said: 'you need to get it in your fingers.' In class (DP), she used personally formed cooperative groups (new to her). She said to have 'browsed' through the group logs regularly but not systematically (DC). She said that group work for her students is not sufficient: 'I would love to emphasize group work, but things do not always become sufficiently clear for students and I have to explain in plenary class' (PD). Her initial beliefs (PD) about the context–concept chemistry and about cooperative learning hardly changed through class enactment (DP) and the student learning (DC).

A Cross-Case Analysis for Two Case Groups

The teacher-developers/enactors went through two cycles: the *development phase* and the *class enactment phase*. The process of *developing* innovative student learning material (DMD), a phase in which ample opportunities exist to exchange experiences (ED), get in contact with and discuss innovations (ED), discuss content and assignments (ED), is important for familiarization and ownership (PD). Reflection on developed materials (DMD) and discussions to improve these (ED), the interplay between the personal domain, the external domain and the developed material domain, leads to new PCK knowledge and beliefs (PD).

The teacher-enactors did not go through the development phase and therefore missed out on the rationale of innovative aspects. This resulted in changes in the module even before class use.

The implications for the *class enactment phase* for both groups of teachers will be argued in the next section.

The Extended Model of Teacher Professional Growth

Combining the model for the *development phase* (Fig. 2) with the model for the *class enactment phase* (Fig. 3) results in the Extended Interconnected Model of Professional Growth (EIMPG), as depicted in Fig. 4.

Teacher learning in the *development phase* takes place through enactment and reflection interactions of the personal domain and two other domains, the external domain and the developed material domain.

During the *class enactment phase*, experiences in the domain of practice may lead to noticeable student learning outcomes (domain of consequence), and this in turn will influence the personal domain.

One aspect in the model shown in Fig. 4 has not been discussed so far: the transition from the *development phase* to the *class enactment phase* (arrows 7, 8). This can be seen as an *intermediate phase*. This *intermediate phase* plays an important role as it is here where teachers decide to take the developed material to class. The teacher-developers/enactors prepared concurrently with the development of the learning material for class use of this material, and this facilitated class enactment. These teachers did not change the learning material after reflection in initial practice (arrows 7, 8) as they discussed meaning of the activities in terms of student learning. For the teacher-enactors, the *intermediate phase* is more vulnerable in the sense that they are more likely not to class enact the material as is (arrow 8), and it is more likely that they will make changes in the material after initial use (arrow 7).

Conclusion and Discussion

To answer the research question, two teacher groups have been studied: Teacher-developers/enactors who developed student learning material from scratch, based on context-based chemistry, and thereafter enacted this in class did acquire new knowledge and beliefs (PCK) and in the second group, the teacher-enactors who merely class-enacted the learning material learned little about the innovation and hardly developed PCK.

The model to understand and interpret teacher growth is based on the observations that developing student learning material and subsequent class enactment leads to changes in knowledge and beliefs of the teacher-developers *because* of the combination of the two phases, the *development of student learning material* followed by *class enactment*. This resulted in the Extended Interconnected Model of Professional Growth (EIMPG) as shown in Fig. 4.

The *development phase* in this model—the interactions between the personal domain, the external domain and the developed material domain—in this extended model shows that the development of learning material allows for multiple cycles of presentation and reflection on knowledge (Penuel, Fishman, Yamaguchi, & Gallagher, 2007), in which teachers get to understand the goals of the renewal (Pintó, 2005), and in which their knowledge and beliefs are taken as starting points (Coenders et al., 2008). The teacher-developers/enactors make their PCK explicit through reflection about their practices (Bindernagel & Eilks, 2009). The iterative and cyclic process of developing material and discourse about this material leads to new knowledge and beliefs.

Clarke and Hollingsworth (2002) distinguished so-called change sequences consisting of 'two or more domains together with the reflective or enactive links connecting these domains, where empirical data support both the occurrence of change in each domain and their causal connection' (p. 958), and 'growth networks' when a change is more than momentary. This last is seen as professional growth.

Our data in relation to the *development phase* in this extended model, the interactions between the personal domain, the external domain and the developed material domain, support the argumentation that the changes during this *development phase* can be seen as 'change sequences,' as teacher-developers are still anxious about the outcomes of class enactment. Teacher growth is still vulnerable and not firmly established.

Moreover, two other advantages of this development phase can be mentioned. Firstly, discourse at network meetings facilitates implementation by seeking 'how-to-do' advice, also with respect to new teaching approaches and materials (Doyle & Ponder, 1977). Secondly, the 'teacher as developer' process narrows the gap between the ideal and the operational curriculum (Van den Akker, 1998). The teacher-developers/enactors interpret the ideal and written curriculum materials concurrent with the development of the material.

The *class enactment phase* in this extended model—the interactions between the domain of practice, domain of consequence and the personal domain—shows the consequences of enacting the material in class. In terms of Clarke and Hollingsworth (2002), the *class enactment phase* leads to 'growth networks' for specific aspects of teacher-developers' knowledge and beliefs. Teachers practice new teaching strategies and experience how the material supports student learning, and this leads to more durable learning. Three different kinds of class results may surface: (a) a student learning result envisaged and hoped for by the teacher-developers does occur; (b) a learning result envisaged and hoped for does not materialize; and (c) a not anticipated learning result is observed. When a student learning result was anticipated and indeed does take place, teachers' knowledge and beliefs will be reinforced, and this will lead to a 'growth network' for given aspects of teacher knowledge. When a student learning result was anticipated but does not materialize, a cognitive conflict arises. Teachers may revert to their previous knowledge and beliefs, but it is also possible that the teachers can explain why the anticipated learning does not take place and can indicate how the materials can be adapted to repair this. This will also lead to lasting new knowledge and beliefs, in other words to 'growth networks.' When a not anticipated learning result does take place, teachers will try to attribute this to specific elements in the material or to the learning process, which may lead to 'change sequences' or to 'growth networks.'

The implications of this EIMPG model for professionalization programs to prepare larger numbers of teachers for a curriculum renewal are that it is possible to predict teacher learning and that it might be most effective to set up regional teacher development teams (TDT) in which teachers from different schools under the guidance of a university teacher educator *re-develop* existing innovative student learning material and subsequently enact this in their classes. This ensures that both the *development phase* and the *class enactment phase* are addressed.

However, a number of questions still need to be answered. How much re-development of existing learning material in a TDT is necessary to ensure teacher ownership and PCK learning? How much time is needed for teachers to familiarize themselves with the rationale of a new curriculum? What is the optimum number of teachers in a TDT?

The first seeds of changes in knowledge and beliefs are planted in the external domain. What components should this external domain consist of in order to provide sufficient new ideas, practical advice and tools to re-develop innovative student learning materials? And how should the development process look like both to have sufficient time for the development of the material and to allow the teachers to concurrently prepare for class enactment of this material?

Future research will have to clarify these issues.

This study is limited in that only two relatively small groups of teachers were involved. Future research on teacher learning in teacher development teams is necessary to generalize the findings of this study: Are the two phases, the *development phase* followed by the *class enactment phase*, instrumental for teacher learning, and is the Extended Interconnected Model of Teacher Professional Growth valid to analyze, describe and predict teacher growth?

Appendix

Time frame showing when the interviews were conducted.

Teacher-Developers

Interview 1 Questionnaire	Development of module	Interview 2	Class enactment of the module	Interview 3

Teacher-Enactors

Introductory workshop	Interview 1	Class enactment of the module	Interview 2

Interview Themes

During interview 1, questions related to how context-based chemistry is perceived, how their role and their students' role are perceived, and with what teaching methodology the respondent is familiar were posed.

Interview 2 for the teacher-developers focused on what the respondents think class use will bring, with special emphasis on what they consider strong and weak, difficult or critical, and innovative aspects of the module.

Interview 3, and interview 2 for the teacher-enactors, zoomed in on class experiences. A number of questions were rather factual such as ‘did you make any changes in the module before use, and if so why?’ and ‘did you use cooperative learning?’ Others were more reflective like ‘how do you now, after class enactment, perceive context-based chemistry education?’

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